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A BIOLOGICAL ANALYSIS

—OF THE—

MONTREAL WATER SUPPLY DURING THE PERIOD FROM NOVEMBER, 1890, TO NOVEMBER, 1891.

BY

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(*Reprinted from the Montreal Medical Journal, August,* 1894.)

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The following account of a biological analysis, made three years ago, has been abridged from my report addressed at the time to Mr. B. D. McConnell, then Superintendent of the Montreal Water Works, who took a deep interest in the investigation. Chemical analyses were made at the same time by Prof. R. F. Ruttan and Prof. Phister.

PLAN OF INVESTIGATION.

I. Regular monthy examinations of samples of water from the following four localities :

1. The lower reservoir.
2. The settling basin.
3. A point near the intake of the St. Cunegonde Water Supply.
4. A point in the middle of the River St. Lawrence south of Nun's Island.

These examinations were made at the express order of the Water Committee with a view of determining whether the water

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* Published by permission of the Water Committee of the Montreal City Council.

obtained from localities 3 and 4 would be preferable to that furnished by the present intake on the north shore of the St. Lawrence, just above the Lachine Rapids.

In addition, I found it necessary to make :

II. Examination of tap water obtained from various points within the city, from the upper reservior, and from the aqueduct,

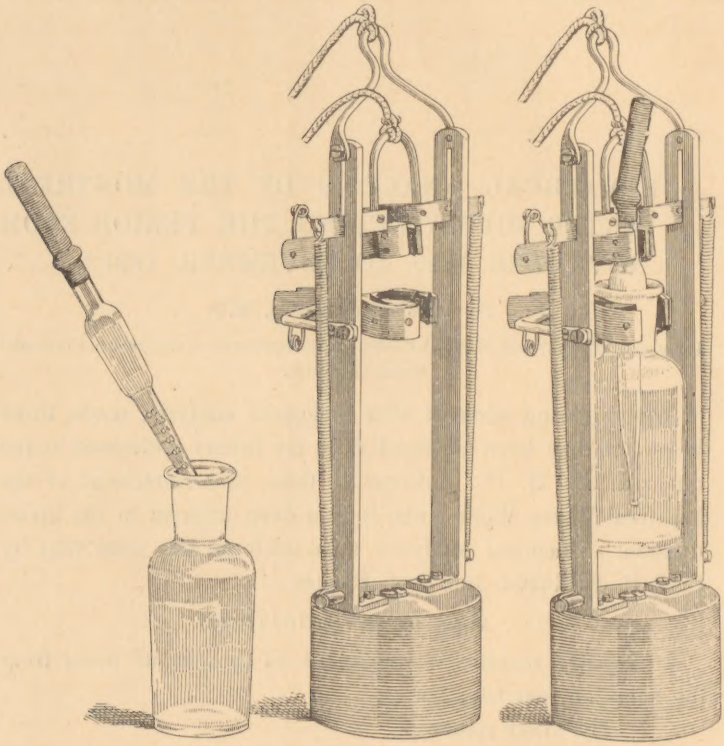

Fig. 1.

to see whether evidences of local contamination existed and to trace the effect of temperature, rainfall and water level.

III. Examination of the water of the St. Lawrence and Ottawa rivers at points above Montreal, to see whether the influence of the sewage from the towns along their banks was perceptible.

IV. Examination of surface waters from other parts of Canada, and especially from uninhabited districts.

METHODS.

A large proportion of the work consisted in the estimation of the number of bacteria present. (Quantative bacterial analysis.) The nature of the bacteria was also studied, as far as the time limits of the analysis permitted. Cultures, for quantitative work, were for the most part made in slightly alkaline, 10 p.c. beef peptone gelatine, made after Lœffler's formula, and grown at 20°C. The samples were taken 10 to 20 feet below the surface, by means of an apparatus shown in figure 1, and were plated in flat glass vials. The cultures were, as a rule, made within a few minutes of the time of taking the samples, and in a few instances, when about an hour or two intervened, the samples were kept in an ice box.

The sediments were all examined microscopically, and during four months the microscopical organisms present were estimated quantitatively by the Sedgwick-Rafter method.

SOURCE OF SUPPLY.

Before giving the details of the analysis, it might be well, in order to make the report intelligible to those who are not familiar with the local conditions of the Montreal water supply, to briefly mention the character of the water, and the topography of the district from whence it is obtained.

Although taken from the north shore of the St. Lawrence river, the Montreal water supply is derived, during the greater part of the year, from the Ottawa, which enters the St. Lawrence from the north at a point about 20 miles above the intake, and forms a belt of dark water close to the shore, the border between this water and the clear green of the St. Lawrence proper being very distinct, though varying in position with changes in the direction and force of the wind and the relative level of the water in the two rivers. During the winter owing apparently to an ice-jam, the Ottawa passes to the north of the island of Montreal, so that the Montreal supply during the months of January, February and March consists of nearly pure St. Lawrence water.

Ottawa River.

The Ottawa river drains an area of over 60,000 square miles

(rather less than the Danube), most of which is entirely uninhabited. Its discharge has been estimated at 60,000 cubic feet per second. Its average width for the 100 miles above Montreal is somewhat over half a mile. At 25 miles above the city it expands into the lake of Two Mountains, varying from 2 to 4 miles in width, and 4 miles above the intake, into Lake St. Louis, 4 to 7 miles wide. There are rapids and falls 60 and 30 miles above Montreal. At many points between Ottawa and Montreal navigation is impeded by enormous sawdust beds from the Ottawa saw mills.

The population along its course, according to the census of 1891, is about 300,000, or 6 per square mile, of which about 100,000 is comprised in cities or towns of over 1,000 inhabitants, the remainder being rural. The chief centres of population and their distances above the Montreal intake are as follows:

Pembroke	4,401	220 Miles.
Renfrew	2,611	190
Perth	3,136	180
Smith's Falls	3,864	175
Aylmer	1,945	140
Ottawa (and Hull)	55,429	125
Buckingham	2,239	100
Hawkesbury	2,042	60
Lachute	1,751	50
St. Anne	1,500	20
Lachine	3,167	4

The Ottawa water is dark, and contains a large amount of peaty pigment, giving the water, when in a deep column, a tint suggesting that of porter. Apart from this it is stated by Prof. Ruttan to contain almost no organic matter. It is much softer than the St. Lawrence water.

St. Lawrence River.—The St. Lawrence drains an area of 510,000 square miles (half as much as the Mssissippi). Its discharge, before receiving the Ottawa, has been estimated at 500,000 cubic feet per second. Apart from the cities and towns, situated upon the Great Lakes or on streams draining into them, the total population of the towns and villages of over 1,000, situated upon the river proper, amounts to about 55,000, of which Kingston (20,000) is really in Lake Ontario. The

populations and distances above the intake at Montreal are as follows :

Kingston	20,000	185 Miles.
Gananoque	3,669	150
*Clayton	4,400	130
*Prescott	2,920	120
*Ogdensburg	11,662	120
Cornwall	6,085	70
*Valleyfield	3,315	35
*Beauharnois	1,590	20

Towns marked * are on the south side of the river.

The river averages fully one to two miles in breadth during the whole of its course, and expands into Lake St. Louis, 4 to 7 miles wide, just above the intake, and into Lake St. Francis, 8 miles wide, 35 miles above. There are rapids at points 20, 25, 30, 35, and 80 miles above the intake.

The St. Lawrence water is clear and light green in colour, and is fairly hard.*

In both these rivers the temperature falls to the freezing point in winter, even at points near the bed of the stream.

I. Monthly Examination of Water Supply.

Microscopical Analysis.—The method employed was, at first, that of simply allowing the sediment to settle in a conical glass, and by means of a pipette placing a little of it under a microscope. This gives a general idea of the constituents of the sediment, but affords no information as to the quantity in which the different organisms are present. In the Sedgwick-Rafter method (which unfortunately only became known to me after the analysis was completed) a given

* The following table compiled from Dr. Ruttan's analyses shows the average chemical composition of Ottawa and St. Lawrence water (quantities in part per million) :

	Color. Lovibond scale.			Solids.			Nitrogenous Matter.			Oxygen consumed on 80°F.		Hardness (as Calcium Carbonate.)	Chloride (as Chlorine.)
	Red.	Yellow.	Blue.	Total.	Loss on ignition.	Ash.	Free Ammonia.	Albumenoid Ammonia.	Nitriates.	15 min.	4 hrs.		
Ottawa.	1.7	5.4	0 04	52	24	28	0.02	0.12	0.03	3.7	6.4	55	1 5
St. Lawrence.	0.1	1.0	0.47	142	69	74	0 01	0.09	0.09	0 5	1.2	102	3.5

quantity of the water, usually 500 cc., is filtered through sand and the sand with the organisms retained in it shaken up with a definite quantity of distilled water, 1 cc. of this is then placed in a glass cell, leaving a superficial area of 1,000 square millimetres and a depth of 1 millimetre. By examining under a microscope, into the eye piece of which a diaphragm has been fitted covering exactly 1 square mm. with the objective employed, each microscopic field represents a fixed unit of measurement with reference to the original water, and the number of each different organism per cc. can be calculated from the average number present in each field. As a rule the genera only are determined. This method is not applicable for determining the number or character of the bacteria.

During the period from March to November, 1891, the presence of the following organisms was noted. The numbers represent the number of different genera found in one sample and not of individual organisms per c.c. :

Month 1891.	Mar.	Aprl.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.
Sample from :									
Reservoir	*	6	12	16	*	8	8	5	9
Settling Basin.	5	3	15	9	*	10	5	*	8
St. Cunegonde.	4	4	31	18	13	11	5	5	12
St. Lawrence ..	*	3	3	12	18	14	5	5	9

* Not estimated.

Of these, the following genera were the most frequent :

DIATOMACEÆ. — *Acnanthes, Amphora, Asterionella, Cyclotella, Diatoma, Encyonema, Epithemia, Fragilaria, Gomphonema, Melosira, Navicula, Nitzschia, Pleurosigma, Stauroneis, Surirella, Stephanodiscus, Synedra, Tabellaria.*

CYANOPHYCEÆ.—*Anabæna, Oscillaria.*

OTHER ALGÆ.—*Chara, Cladophora, Cœlosphærium, Conferva, Cosmarium, Palmella, Pleurococcus, Pediastrum, Vaucheria, Volvox, Penium, Protococcus, Scenedesmus, Tetraspora, Zygogonium.*

FUNGI.—*Crenothrix.*

RHIZOPODA.—*Actinocyclus, Actinophrys, Amœba, Gromia,*

INFUSORIA.—*Bursaria, Carchesium, Dinobryon, Epistylis, Euglena, Heteronema, Monas, Paramœcium, Tracheloccerca, Trachelomonas. Vorticella.*

SPONGIARIA—*Sponge spicules.*

VERMES.—*Anguileula, Monostylus, Rotifer, Stylonychia. Stentor.*

CRUSTACEA.—*Alona, Cyclops, Daphnia.*

As I had not been able to employ the quantitative method during the year of analysis, I give the results obtained, per c.c., from tap water during the period from April 10th to June 4th, 1892, in the following table :

Date of examination	April 30.	May 6.	May 15.	May 28.	June 4.
Number of sample	62	63	64	65	66
DIATOMACEÆ.	**64**	**84**	**56**	**42**	**322**
Acnanthes	2	0	0	0	0
Amphora	3	pr	0	0	0
Asterionella	21	36	18	12	20
Cocconeis	0	0	0	1	0
Cyclotella	pr	pr.	2	0	1
Cymbella	1	pr.	0	0	0
Diatoma	2	0	pr.	0	0
Encyonema	0	0	2	0	0
Fragilaria	pr	6	pr.	2	0
Gomphonema	1	pr.	pr.	0	0
Grammatophora	0	0	0	pr.	0
Melosira	23	24	21	2	5
Navicula	9	9	pr.	1	300
Nitzschia	0	4	11	2	0
Surirella	0	0	1	0	0
Synedra	2	4	0	22	1
Tabellaria	0	3	0	0	0
ALGAE.					
Chlorococcus	0	32	0	0	0
Protococcus	0	2	1	0	0
Zoospores	pr	pr.	pr.	pr.	10
INFUSORIA.					
Monas	0	2	pr.	0	0
MISCELLANEOUS.					
Starch grains	3	2.5	2	2	4.5

I have omitted from the table the following genera which, though occasionally seen, were never present in an amount equal to 0.5 per c.c. : —*Coscinodiscus, Pleurosigma, Stanroneis, Stephanodiscus, Oscillaria, Arthrodesmus, Cladophora, Cœlosphærium, Conferva, Pediastrum, Pleurococcus, Beggiota, Amœba, Cercomonas, Trachelomonas, Spongilla and Cyclops.*

The organisms were more numerous in the warm than in the colder months. The higher animal forms being only met with during the summer.

Pollen grains (most commonly from the pine) and vegetable

fibres were usually present in traces, and were most constant in the samples from the reservoir.

From the above results it will be seen that while the waters contain small amounts of the non-bacterial organisms common to all surface water, these were never found in sufficient quantity to affect the odor, taste, or hygienic quality of the water. Of the organisms, the diatoms Melosira and Asterionella were the only ones occurring constantly in any appreciable quantity.

The green organism (Anabœna) which abounds in the water of Lake Ontario and the Bay of Quinte during the summer, was scarcely detected at Montreal, though owing to the infrequency of the periods of collecting samples it may have been missed. Though present in the reservoir during August and September very little appeared to enter the supply pipes.

The results of examination of sediments, on the whole, were decidedly satisfactory from a hygienic point of view.

Starch Grains.—The only anomalous features presented by the sediments was the constant occurrence of starch grains in the sediment of most of the samples. These I first noticed in the May samples, they being present in the water from the reservoir, settling basin and St. Cunegonde, but not in that from the St. Lawrence.

These grains were usually round or slightly oval, or in some cases presented blunted angles. They measured 12 to 30 microns in diameter, stained blue with iodine solution and polarized with a central cross. Some showed a central fissure in the form of a slit or cross, and often lamination could be distinctly made out.

I was at first disposed to regard them as an accidental contamination, due to the entrance of dust into the samples, but this was shown not to be case by the fact that upon filtering water directly from the tap through glass wool, compressed into a small strainer, the starch was invariably detected, while the materials employed as well as the glass-ware used, showed no signs of it.

Upon consulting the standard works on water analysis, I was unable to find any reference to the presence of starch in water otherwise than as a consequence of contamination by sewage proper, kitchen refuse, or the waste of industrial establishments. On the other hand, all the other results of my analysis were strongly opposed to the theory of contamination of the water.

Being myself unable to identify the grains satisfactorily with any of the known starches, I consulted Prof. D. P. Penhallow, of McGill University, who examined them carefully and called my attention to the fact that they corresponded in size and shape and structure to corn starch grains, and were much larger than any of the starch grains found in aquatic plants. He stated that, in his opinion, the only starch bearing aquatic plants at all likely to lead to dissemination of starch grains in the water were the yellow and white water lillies (*Nymphœa* and *Nuphar*) the starch grains of which, however, never exceeded 13 microns in diameter, and were readily distinguished, by their form and arrangement, from the granules under consideration.

If the grains were corn starch then they must have come from some starch factory or grist mill.

There were, however, no starch factories or large milling industries along the banks of the Ottawa, and though some starch factories are situated upon the St. Lawrence, none of the grains had been found by me in that water.

Upon estimating the number of starch grains per cc., I obtained the following results, for different seasons of the year, from samples of the water which happened to have been preserved :

Month.	Mar.	Aprl.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.
Sample.									
Reservoir......	*	pr.	*	2	*	*	*	3	2
Settling Basin.	0	*	*	pr.	*	1	*	*	2
St. Cunegonde.	0	*	0.8	4	4	*	*	5	2
St. Lawrence..	*	*	*	0	0	*	*	0	0

* Not examined.

The largest amount of starch ever found in any sample was 7 granules per c.c., in a stagnant rusty sample, obtained from a street hydrant.

The presence of the starch in the Ottawa water and its absence from the St. Lawrence, was a matter which completely puzzled me. Examination of the starch granules of the sweet

Fig. 2—Starch grains from water.

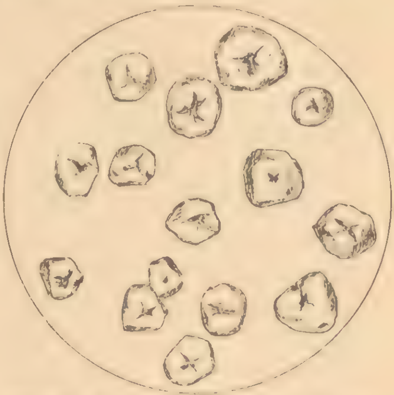

Fig. 3 Starch from white pine bark.

Fig. 4—Starch from white pine bark after soaking in water.

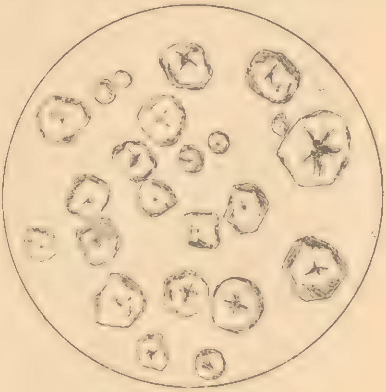

Fig. 5—Corn starch.

flag root and wild rice, showed that these grains were altogether too small to be thought of as a possible source.

At this point, Prof. G. P. Girdwood, of McGill University, suggested to me the possibility that as starch is present in the

bark of some of the coniferous trees, it might be derived from the white pine lumber which, as already stated, is sawn in such large quantities as to block the Ottawa river in places with vast beds of sawdust. Upon my examining white pine bark, I was delighted to find not only that it contained large quantities of starch, but that these, though somewhat more angular, closely corresponded in size, shape and structure with the grains found in the water (and closely resembled corn starch).

Upon soaking pine bark for two months in water, many of the starch grains in it assumed the rounded outline typical of the starch of the water sediments, whereas corn starch grains, after the same period of maceration, became fissured and tended readily to disintegrate upon slight pressure.

The appearance of the various grains may be better understood from the accompanying illustrations, figs. 2, 3, 4 and 5.

Starch grains similar to those of the pine were found, though less plentifully in the bark of the cedar, hemlock and spruce.

The following table gives the diameter in micro-millimeters of the various starches examined :

	Diameter in microns.
Water Sediments	11.4 to 28.0
White Pine Bark	8 to 28.0
Corn	5.8 to 27.0
Sweet Flag	6.0 to 13.0
Wild Rice	5.7 to 13.0
White Water Lily	1.9 to 7.6
Yellow Water Lily	3.8 to 13.3

There is nothing to show that the starch forms a dangerous ingredient of the water. I have also found somewhat similar grains under circumstances which did not show any possibility of sawdust pollution, and unless great care is exercised one is liable to meet with them as a result of contamination of the glass-ware, etc., by dust.

My excuse for giving the above results at such length, is that it does not seem to have been recognized as yet that starch

grains may be observed in water independently of sewage or industrial pollution on the one hand, and of errors in manipulation on the other.

Bacterial Analysis.—The opinion entertained by chemists of the Montreal water supply, at the time when this examination was undertaken, is fairly well expressed in Bulletin No. 15 of the Inland Revenue Department at Ottawa, which in referring to the relatively high proportion of organic matter, speaks of it as " capable of sustaining and nourishing, to a much greater degree than in most water supplies, those minute organisms which, while in most cases harmless, are closely related to others known as disease germs. A water so largely impregnated with organic matter, as that of the Ottawa, would become a very efficient nidus for the propagation of morbific bacteria were such organism to find an entrance to it."*

It may be stated in a general way that a pure water should not habitually contain large numbers of bacteria. Although no hard and fast rule can be set, Miquel's scale fairly expresses our present ideas upon the relation of the number of bacteria to the purity of water :

Exceptionally pure	water	contains	0 to 10	per c.c.
Very pure	"	"	10 to 100	
Pure	"	"	100 to 1,000	
Mediocre	"	"	1,000 to 10,000	
Impure	"	"	10,000 to 100,000	
Very impure	"	"	100,000 and over.	

The number of bacteria in filtered water should not, according to Koch, habitually exceed 100 per c.c.

I was agreeably surprised to find that the Montreal water, instead of teeming with bacteria, was conspicuously free from them, as compared with other bodies of running water, so that whatever might be the nature of the organic matter present it did not appear to be specially favourable to bacterial growth.

The following table shows the average number of bacteria found in some well known surface waters, most of which are

* McGill, Bulletin No. 15, Department of Inland Revenue, Ottawa.

used as sources of drinking water. These marked * are filtered before being distributed :

		Locality.	Authority.
Ottawa	220	Montreal	Johnston.
St. Lawrence	360	Montreal	Johnston.
Mississippi	800	St. Louis	Currier.
*Danube	2,000	Vienna	Kowalsky.
Seine	33,000	Above Paris	Miquel.
*Thames	19,750	Above London	P. Frankland.
Croton Aqueduct	4,280	New York	Health Report.
Hudson	3,065	Albany	Prudden.
Potomac	3,774	Washington	Thos. Smith.
Neva	5,772	St. Petersburg	Poehl.
Rhone	75	Geneva	Fol.
Rhine	20,300	Mulheim	Moers.
*Main	2,050	Frankfort	Rosenberg.
*Spree	65,000	Above Berlin	Frank.

Number of Bacteria found each month.—The following table shows the average number of bacteria per c.c. found each month in the reservoir, settling basin, St. Cunegonde and St. Lawrence samples :

Date.	Temperature of water °C.	Level of water at Lachine in feet.	Bacteria per c.c.				
			Reservoir.	Settling Basin.	St. Cunegonde.	St. Lawrence.	Combined Average.
December 1st,'90	4°.	11·1	8	313	473	265	284
January 5th, '91.	0°.	12·0	31	44	30	61	41
February 2nd	0°.	10·9	20	89	63	29	50
March 5th	0°.	12·2	185	164	316	577	310
April 13th	0°.	13·0	171	347	363	161	260
May 4th	10°.9	15·0	79	121	156	324	167
June 2nd	13°.0	13·0	42	189	130	210	142
July 2nd	18°.3	11·5	30	481	197	81	275
August 3rd	21°.0	11·5	92	119	101	85	99
September 7th	18°.3	10·1	21	81	53	53	52
October 1st	13°.1	10·1	40	55	29	43	42
November 25th	4°.	10·5	143	1132	1883	363	930

The following summary shows the maximum, minimum and average number of bacteria per c.c. for each sample throughout the year, together with the dates upon which the maximum and

minimum numbers occurred, and the total number of samples examined from each source :

Number of samples examined.	Source.	Bacteria per c.c.		
		Max.	Min.	Average.
70	Reservoir	286 (Nov.)	9 (Feb.)	78
67	Settling Basin	1900 (Nov.)	32 (Oct.)	278
73	St. Cunegonde..........	2260 (Nov.)	12 (Oct.)	316
71	St. Lawrence	600 (Nov.)	18 (Oct.)	189
281				

The above tables show that during the greater part of the year the number of bacteria per c.c. of the water varies between 100 and 200. During the early part of the summer and in midwinter this number falls considerably below 100, and during the spring and early fall it rises for a short period to between 1,000 and 2,000. These temporary elevations coincide with a period of heavy rainfall which ushers in the winter, and with the melting of the snow in the spring, on both of which occasions the river level rises considerably.

The interval of one month between the taking of samples is so great, that the temporary rise in the number of bacteria might pass unnoticed, if this sample did not happen to be taken exactly at the time when it occurred. Suspecting that this was the case in 1891, I made private examinations of the tap water at intervals of one week, with the result that a rise to 1940 per c.c. (compared with 347 per c.c. in the official sample taken a few days before) was observed, the number falling to 117 by the time the next official collection became due. The number obtained in the official settling basin being 121.

It is evident that the 12 months covered by the analysis comprises the early winter increases in bacteria for both 1890 and 1891, which makes the average number for the year higher than would otherwise be the case.

This spring contamination of the water was also studied in

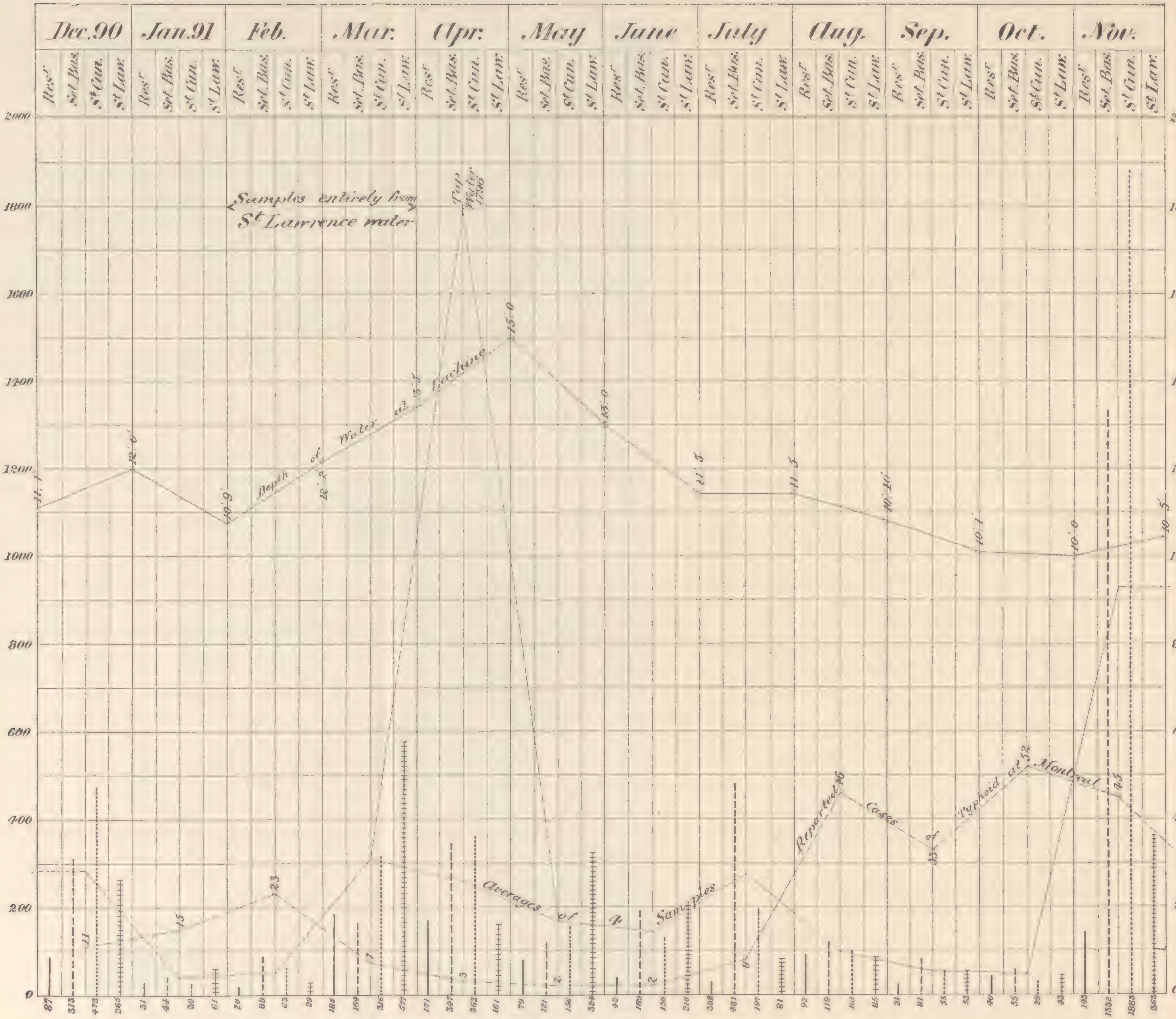

Fig. 6—Diagram showing the results of the monthly examination of water samples.

tap water during April, 1892. The following table shows the variation in the number of bacteria :

Date.	Bacteria per c.c.
April 2	112
9	830
16	2400
26	122
30	46

The two periods characterized by low numbers of bacteria (midwinter and early fall) correspond with seasons when the level is very low.

These relations are shown graphically in Fig. 6.

Although rainfall, when sufficient to produce a marked rise in the water level of the rivers, was found to be associated with an increased number of bacteria, due no doubt to the washings of the soil, no increase was noted corresponding to the ordinary local rainfall.

Comparison of the Four Samples Examined.

Reservoir.— One is struck by the marked superiority of the reservoir water shown by its small number of bacteria, as compared with the other samples. During 9 months of the 12, the number of bacteria was below 100, while the average number was less than one-third of the number found in the settling basin. This, apparently, is due to the beneficial effects of sedimentation, although the reservoir is not well constructed for that process (not having separate inlet and outlet pipes), but chiefly serves to secure a head of water with constant pressure and to form a reserve in case of need. That the reservoir water does not deteriorate, and that its quality remains unimpaired in spite of a large accumulation of mud and slime at the bottom, is a matter which can be readily accounted for. We know now that the agencies which produce the series of oxidative and nitrifying changes, leading to the self purification of waters, are a special class of organisms (nitro-bacteria) which are most abundant in that very slime which is generally regarded with so much suspicion by the public. To secure the proper perform-

ance of this beneficial process, by which the albumenoid and ammoniacal bodies, products of pollution, are (perhaps after being first decomposed into more readily assimilable forms by the agency of the water bacteria) changed into the more stable forms of nitrates, it is necessary that there shall be a sufficient supply of dissolved oxygen in the water and a sufficient circulation to promote oxidation and check any tendency to anærobic putrefaction. For this reason shallow reservoirs of 15 to 30 feet in depth are better than deeper ones.

Sunlight has been supposed to act powerfully in keeping in check any tendency to bacterial overgrowth, but although I have not yet been able to practically test the matter, it seems probable that the opacity of the Montreal water supply in summer would render the effect of sunlight very slight.

That the improvement which reservoir waters undergo during sedimentation is not merely due to a mechanical sinking of the bacteria, is shown by the fact that the number found in the deeper strata does not show any corresponding increase. This was seen in the following observations :

		Depth.		Bacteria per c.c.		
		From surface.	Above bottom.	Max.	Min.	Average.
Lower Reservoir..	(South Basin)..	10	15	66	43	54.3
No. 564.......	Oct. 2, 1891.	24	1	86	55	67.3
Lower Reservoir.	(North Basin)..	10	15	....		16.0
No. 564a.......	Oct. 2, 1891...	24	1	20	15	17.5
Lower Reservoir..	(South Basin)..	5	20	236	180	203.0
No. 570........	Nov. 29, 1891.	10	15	246	214	238.0
		20	5	248	96	172.0
		24	1	182	148	165.0
Lake St. John. ...	(Roberval)	5	40	57	9	24.2
No. 555........	Oct. 7, 1891...	40	5	27	8	17.6

From what we know of nitrification in waters, the ideal bed for a reservoir should be coarse sand or gravel rather than of bare masonary or cement, but as a matter of fact the natural sediment from the water furnishes abundance of the nitrifying agent.

Settling Basin.—This term as applied to the pond at the wheel house is a misnomer, as the current is always so rapid as

to allow of very little settling, and, as a matter of fact, the number of bacteria found there was never noticeably less than that in the aqueduct. From a biological point of view the plan suggested by the Superintendent of having a separate channel for the water used in obtaining power for pumping, and of greatly enlarging the settling basin seems to be an absolute necessity. At present the water is pumped into the mains with very little settling at all, while only a small proportion of it ever passes through the reservoir. I might point out that the question of what should be the proper dimensions of the settling basin is a biological as well as an engineering one, and a series of examinations should be made to find out what amount of surface area would be sufficient to secure, by sedimentation, the requisite reduction in the number of bacteria*.

St. Cunegonde.—The samples from the St. Cunegonde source in the Nuns Island Channel showed about the same number of bacteria as those from the settling basin, and were decidedly inferior in quality to both the reservoir and St. Lawrence water.

Evidently the theory of the supposed superiority of this water arose through a mistaken interpretation of the chemical analyses by the Inland Revenue Department, and simply consists in a lessened amount of organic matter due to larger dilution by the St. Lawrence water. As the organic matter, characteristic of the Ottawa water, has been shown by Dr. Ruttan to be of the nature of a harmless pigment (crenic and apocrenic acids), the most exact proportion in which it may be present is a matter of indifference from a sanitary point of view.

That the mere passage over the rapids in anyway improves the water by oxidation has never been demonstrated, and as we now know that the oxidation of water is not simply a matter of aeration, but is due to the action of the nitrifying bacteria, there is no longer this theoretical argument in favour of this point of supply.

On the other hand, a special investigation, made jointly by

* The question of the undesirable proximity of the garbage depot to the settling basin had not arisen at the time when this analysis was made, and I have since had no opportunity of investigating the matter.

Dr. Ruttan and myself in July, 1891, brought to light facts which show that the intake of the St. Cunegonde supply is not very favourably situated.

The discharge from the tailrace, which empties into the Nuns Island channel 150 yards above the St. Cunegonde intake, brings with it the contents of the river St. Pierre. This little stream receives the drainage of all the land lying to the north of the canal between Montreal and Lachine, with the result that its water half a mile west of Cote St. Paul was found to contain over 13,000 bacteria per cc. A little further on it receives the washings of the West End Abattoir. This addition gives the water a very offensive character, and I found it to contain 172,000 bacteria per cc. In examining the tailrace water upon several occasions I never failed to detect floating portions of offal and animal debris. After receiving the tailrace water this number was reduced to 92,500 per cc. owing to the dilution.*

As the discharge of a large volume of this filthy water at a point 450 feet above the St. Cunegonde intake which is situated, 900 feet from the shore, was so obvious an objection, I made, jointly with Dr. Ruttan, an examination of samples obtained on July 7th, 1891, at 5 points in the line between the shore and the intake in order to see how far out the zone of pollution extended. The wind was off shore and its velocity 15 miles per hour. The water level was fairly high in the channel. The water close inshore opposite the intake contained 69,000 bacteria per cc.; at 100 feet out it contained 669 per cc.; at 200 feet out it contained 238 per cc.; and at 400 feet 157 per cc. The number obtained from a sample of tap water at the pumping station was 127 per cc. which one would expect in pure water.

The chemical results obtained by Dr. Ruttan showed marked pollution inshore and at 100 feet, with slight pollutions at 200 feet and none at 400 feet, thus corresponding closely with the biological result.

It is evident that on that occasion the zone of pollution

* This contamination of the tailrace has no bearing upon the Montreal supply as he water only becomes polluted after leaving the settling basin.

ceased between 200 and 400 feet from the shore or 500 and 700 feet from the intake, and it is unlikely that under ordinary conditions the contents of the tailrace enter the St. Cunegonde supply. Still, as under altered conditions of the current, water level or bed of the river it is not impossible that this may occasionally happen, especially when the shallow flats lying inshore are packed with ice.

It would seem safer to divert the drainage of the St. Pierre into the city sewers, though I never found any evidence of such pollution in the samples examined.

I was not able to detect any evidence of pollution from the tanneries either in the water or the ice of this locality, but the probability that the Verdun shore may soon become densely populated is a further objection to the site.

An interesting point in the analysis was the increase in bacteria, was almost entirely caused by a species apparently identical with the colon bacillus. Corresponding with this increase there was a falling off in the proportion of the *Bacillus fluorescens liquefaciens*, which formed from 30 to 40 per cent. of all the colonies in the pure water of the river and only 0.5 to 1.0 per cent. of those in the polluted water of the tailrace. At 100 feet out the proportion of *B. fluorescens liq.*, rose to 12 per cent. at 200 feet to 25 per cent. and at 400 feet to 33 per cent. It would seem that any unusual deficiency of the proportion of this organism to the total colonies during summer should be regarded with great suspicion.

St. Lawrence Water.—The results of the examinations do not show that this water is better from a sanitary point of view than the present city supply, as far as can be judged from the number of bacteria and the nature of the sediment. Although informed that the line of the pure St. Lawrence water would always be met with at a point 800 feet south of Nun's Island, I have on two occasions seen the Ottawa water extend as far as 1500 feet south of the island. Of the St. Lawrence water it can safely be said that it is a perfectly clean and pure river water. One point in favor of the St. Lawrence is that it is far less

affected than the present city supply by temporary pollution due to heavy rainfall or melting snow.

II.—Examination of Local Conditions Affecting the Montreal Water Supply.

Tap Water.—In order to determine whether the water as supplied by taps was similar in quality to that of the mains, numerous samples were examined during July and August of 1891. The taps were in all cases allowed to run for at least 30 minutes before samples were taken and two or more samples were always examined, in order to make sure that the number obtained was typical for the day. Besides taking samples each day from one special tap which was allowed to run continuously, I made frequent examinations from taps in various parts of the city.

The tap water was found to contain practically the same number of bacteria as the water of the settling basin and, as a rule more than that of the reservoir. The number of bacteria was found as a rule remarkably constant, irrespective of the points from which the samples were obtained. Usually, but not always, the taps on the circuit supplied by the upper reservoir (the water from which is pumped up from the lower reservoir) contained fewer bacteria than those in the lower circuit. I have given the results in the following table.

Comparison of Upper and Lower Circuit

Date.	Number of Bacteria per cc.	
	Lower Circuit.	Upper Circuit.
1891..		
May 1		
" 8	306	117
" 14	210	66
" 22	146	105
June 23	50	18
" 30	30	22

As far as it goes this supports the view that the water is improved by standing in the reservoir.

During July the daily examination showed for the upper cir-

cuit a maximum number of 136 bacteria per cc. and a minimum of 28, the average being 68. During August the maximum was 160 per cc. the minimum 17 and the average 55.

A comparison was made of the water from the lower and upper circuits with the following results.

	Lower Circuit.		Upper Circuit.	
	Reservoir.	Taps.	Reservoir.	Taps.
Sept. 23 .	39	37	41	50
Oct. 2.	53	49	29	54

Although this shows relatively slightly more bacteria in the upper than the lower circuits, the difference is not large enough to be outside the limits of experimental error.

Aqueduct.—Two examinations of samples taken at 5 points along the aqueduct gave :

	Aug. 7.	Sept. 12.
Maximum	173	102
Minimum	93	38
Settling Basin	224	113
Lachine Intake	115	80

The variation is not sufficient to show any material change in the water during its passage from Lachine.

Dead Ends.—In districts where the circulation in the mains is not complete complaints are often made of turbidity of the water. This turbidity appears to be due to rust from the mains but as the consumers are inclined to consider this condition as unwholesome, I made on Aug. 24th, 1891, an examination of the water from 11 different districts supplied from dead ends. The average number of bacteria found per cc. was 94, and therefore such as to exclude any idea of a polluted or stagnant state of the water. The vital statistics from the streets supplied by dead ends do not show any greater frequency of typhoid than other parts of the city. Iron rust is, as we know used as a means of precipitant for freeing water of organic matter.

III.—Study of the River Water at Points Above Montreal.

Ottawa Water.—In order to study the influence of the towns along the course of the river upon the character of the water, two sets of examinations were made in 1891, one on July 3rd, and the other on Sept. 24th. Samples were collected from the bow of a steamboat by means of a fishing rod and line to which small weighted bottles were attached, and the cultures made immediately. Duplicate samples were taken at 15 points on each trip, and a sample was also obtained from lake Des Chenes, 10 miles above Ottawa. Owing to an accident, several of the cultures made during the first trip could not be made use of. The results obtained are given in the following table together with the distances below Ottawa.

	Distances below Ottawa.	Bacteria per cc.
Above Ottawa (C.P.R. Bridge)......	0 Miles.	170
Gatineau.....	5 "	686
Cumberland	30 "	1530
Grenville.............	65 "	48
Carillon..............	80 "	60
*Como	90 "	72
*St. Anne.......................	100 "	11
Lynch's Id.........................	120 "	49

*In lake of Two Mountains.

These are shown graphically in Fig. 6.

This showed a marked increase in the number of bacteria below the city of Ottawa, diminishing to the normal for river water by Grenville and reaching a minimum in the lake of Two Mountains, and increasing slightly in the river channel below St. Anne. None of the smaller towns appeared to have any perceptible pollutory effect on the water.

In the second test on Sept. 24th and 25th, a much more thorough examination was obtained, but the results corresponded to a remarkable extent with those of the former examination. I have given the table in full in order to show the measure in which samples taken from the same points on two succeed-

ing days resembled one another in regard to the number of bacteria :

Locality.	Up Trip.			Down Trip.			Combined Average of both trips.
	Max.	Min.	Aver.	Max.	Min.	Aver.	
Lake Des Chenes.				6	4	5.2	
Mil's below Ott'a.							
2	580	378	479	365	250	307	393
5	528	500	509	732	329	532	520
10	460	272	377				
15	155	123	140				
20 Cumberland.	172	130	147	176	139	152	149
30 Thurso	314	134	257	172	72	122	204
50 Montebello..	47	46	46	45	24	34	40
60 L'Orignal....	40	26	33	45	24	34	33
65 Grenville....	26	19	23				
80 Carillon	37	31	36	38	26	32	34
90 Como ..	18	10	14	28	16	22	17
92 Oka .... } Lake of Two M'ts			17	8	5	6	12
100 St Anne	10	6	8	16	0	8	8
105 Lynch's Id.	21	15	18	22	14	18	18
120 Lachine	18	8	12				

This is shown graphically in Figs. 7 and 8.

A point to which Dr. Ruttan was the first to call attention is that the thickly settled agricultural district composed by the counties of Pembroke and Russell, having a population of about 100,000, drains into the Ottawa. An examination of water of one of the large streams for this district, the South Nation river, was made by us in May 1892, but no evidences of pollution were detected.

From this it is evident that any pollution due to the Ottawa or other sewage is effectually got rid of long before it reaches Montreal. The greatest improvement apparently takes place in the Lake of Two Mountains the bacteria being much fewer at the lower than the upper end. Attention may also be called to the fact that the number of bacteria in the water of the Lake of Two Mountain is lower than that of the present Montreal supply which on Sept. 23rd, gave 30 to 49 per cc.

That St. Anne, and upper Lachine with the intervening population along the banks of the St. Lawrence do not form a

possible source of infection for the Montreal water supply is by no means clear as our water is taken from the portion which flows by the north bank of the St. Lawrence. It seems advisable that a careful sanitary inspection of this district should be made

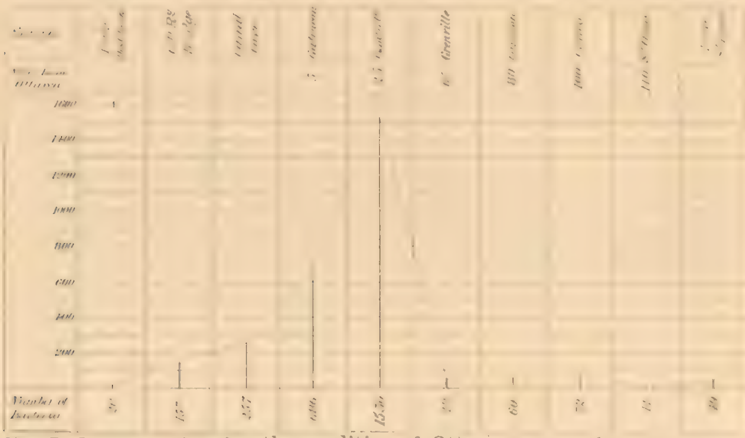

Fig. 7—Diagram showing the condition of Ottawa water above Montreal. (First examination, July 30th, 1891.)

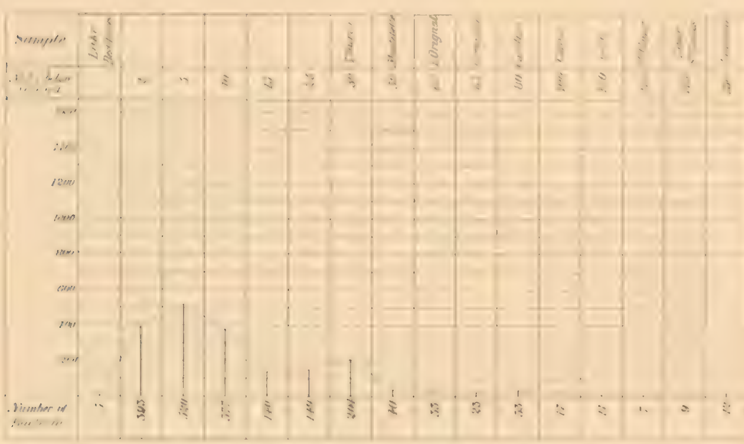

Fig. 8—Diagram showing the condition of Ottawa water above Montreal. (Second examination, Sept. 24th, 1891.)

and a map prepared showing the position of all privies, barns, etc., in order that any possible source of infection should be eliminated. The key to the safety of the Montreal drinking supply may be said to lie between St. Anne and the intake.

The entrance to the intake is confidingly placed so as to catch all washings from the adjacent portions of the lower Lachine road.

Question of typhoid infection.—The following inquiry into the possibility of water-borne typhoid in connection with the Montreal water may be of interest:

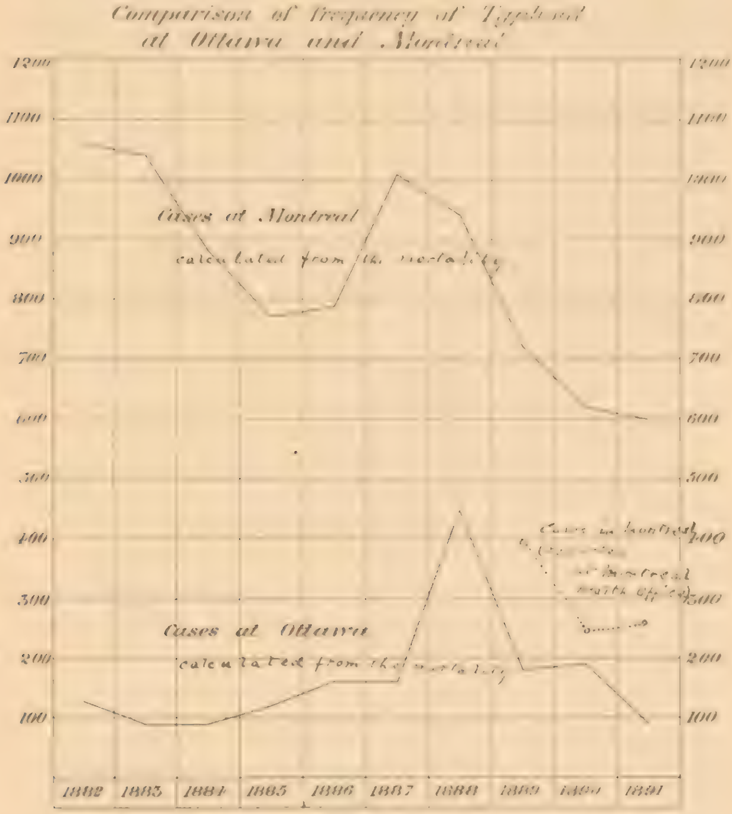

Fig. 9.

The number of cases reported each month at the health office are shown in figure 6. It is evident that if the frequency of typhoid fever depended upon general contamination of the water supply, it would, allowing for the period of incubation, be expected to appear in the month following the greatest contamination of the water. As no increase in typhoid occurred in these

months, that disease being most prevalent when the number of bacteria in the water reached its lowest point, it is evident that the turbidity and increase in bacteria which periodically affects the Montreal supply is not of such a nature as to cause or predispose to typhoid infection. In this connection it was interesting to see if there was any relation between the frequency of typhoid at Ottawa and at Montreal. Unfortunately non-fatal cases of typhoid are not reported to the Ottawa health office, and it is a well-known fact that less than half of the cases are reported at the Montreal office. As the deaths from typhoid are reported however, I have taken these as my basis, calculating the mortality at 10 per cent. As shown by figure 9 there is not only no constant relation between the frequency of typhoid in the two cities, but that even the severe epidemic of typhoid at Ottawa in 1888, was not accompanied by any increase in the number of cases in Montreal.

It appears therefore that general pollution of the Montreal water as may occur is probably of a harmless nature and does not form a source of infection.

St. Lawrence above Montreal.—A double series of observations was made in the same manner as in the case of Ottawa, the samples being taken on July 27th, 1891, between Brockville and Lachine, and on Sept. 30th, 1891, between Kingston and Lachine.

The results with the distances above the Montreal intake at which the samples were taken, are shown in the following table and in figures 10 and 11:

Sample from	Distance above intake.	Bacteria per cc.					
		July 27th			Sept. 30th		
		Max.	Min.	Average.	Max.	Min.	Average.
Lake Ontario near Kingston	190 miles.	...	...	...	29	16	22
Long Point	180 "	...	...	...	51	48	49
Clayton	175 "	...	...	...	33	25	29
Brockville	125 "	76	14	44			
Galop Rapid	98 "	38	31	37		.	18
Head of Long Sault	75 "	210	70	121		...	76
Foot of Long Sault	68 "	156	141	151			.
Cornwall	65 "	155	90	130	72	56	63
Coteau	35 "	77	26	47	15	10	12
Caughnawaga	2 "	74	49	61	33	20	27

This examination showed an interesting increase in the number of bacteria on both occasions in the swift and relatively shallow stretch of river below Prescott, the number falling again in Lake St. Francis and rising somewhat below Lake St. Louis.

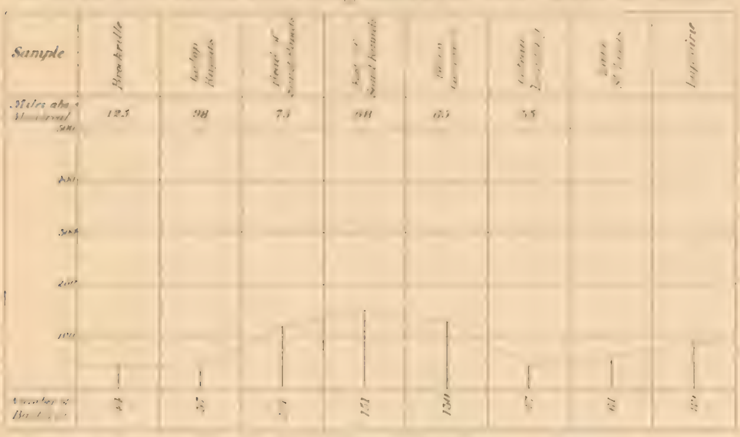

Fig. 10—Diagram showing condition of St. Lawrence water above Montreal. (First examination, July 26th, 1869.

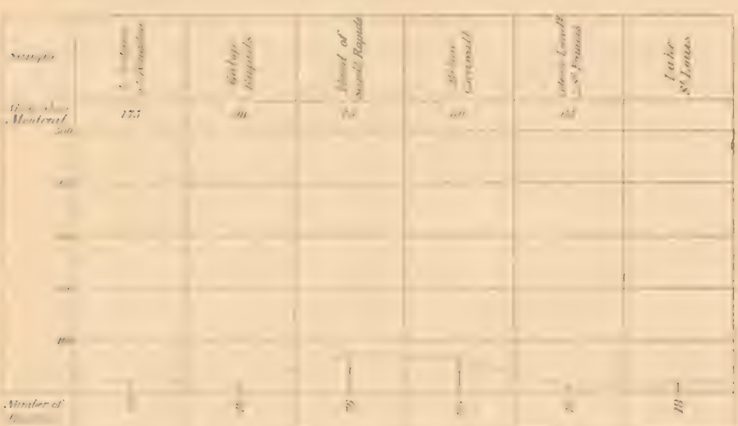

Fig. 11—Diagram showing condition of St. Lawrence water above Montreal. (Second examination, October 1st, 1891.)

It also shows throughout a relatively smaller number of bacteria in the water in September than in July.

IV. Surface Waters in other Parts of Canada.

Water from Uninhabited Districts.—A number of examinations made for the purpose of comparing the Ottawa water with

similar peaty waters for uninhabited districts, may be briefly recorded here by means of the following table, which shows that the water of the large rivers of the far north, coming from a desolate and almost unexplored country, contain as many bacteria as the Montreal water supply. It must be mentioned however that some of the samples were taken during a period of heavy rainfall late in the autumn.

Date.	Sample.	Bacteria per cc. Max.	Min.	Average.	Temperature of water °C.
1891.					
Aug. 30......	Saguenay above Chicoutimi	70	41	56	18°
Oct. 7......	Ouiatchouan	134	101	118	12°
"	Ashuap-Mouchuan	700	100	176	10
"	Mistassini	694	400	474	10

Other Canadian Water Supplies.—Finally it seems of some interest (in view of the scanty data available on the subject) to mention some analysis of other Canadian water supplies which I made during the summer of 1891, though the fact that these waters were not repeatedly examined makes it impossible to draw any definite conclusion as to their relative sanitary value. In each case several different samples were taken and the cultures were, in every case made upon the spot.

Locality.	Date	Number of samples.	Bacteria per cc. Max.	Min.	Average.
Kingston, Ont.........	Sept. 30th, 1891.	8	99	48	65
Quebec, Q.............	Oct. 7th, " .	5	112	86	90
Sherbrooke, Q.........	July "	7	263	85	212
Halifax, N.S..........	July 17th, 1892.	7	218	41	99

I mention these results partly in order to emphasize the fact that for a reliable analysis the water must be repeatedly examined and samples obtained at different seasons. In a recently published biological analysis of 21 Canadian water supplies,* made in the spring of 1894 very different results were obtained,

*E. B. Shuttleworth. Toronto Telegram, May 10th. 94.

he number of bacteria found in the Quebec water, for example, being stated as 1045 per cc. whereas it only contained 90 per c.c. on the occasion when I examined it.

Description of Species of Bacteria Found—Qualitative Bacterial Analysis.

From a sanitary point of view the most pressing questions in connection with my analysis of the Montreal water supply were those bearing upon the possibility of pollution. This can be determined as a rule better by quantitative than qualitative work, and I found that the study of the problems of this nature took up so much time that very little was left for the determining of the species of bacteria present.

Although I isolated over fifty different forms from the water, I was not able in all cases to study them thoroughly enough to identify them with existing species described by others. This identification is a matter of extreme difficulty except in the case of well known and easily recognized forms, and the difficulty is increased rather than diminished by the fact that some workers have published as new species forms which were already described, or described them in so vague and unsatisfactory a manner that it is impossible, from the meagre details given, to tell whether they are new or not. Microphotography does not seem to have greatly helped matters, and with the pigment producing (chromogenic) bacteria, it is impossible to tell from the descriptions given what the shade of colour really is and in how much its tint depends upon the medium employed.

For these reasons, although I detected and described several forms which I consider to be new species, I have hesitated to publish them for fear of adding to the existing confusion.

It seems to me that the great tendency which these organisms have to form varieties and races makes it really of less importance except in the case of pathogenic forms to multiply the number of new species by emphasizing minute points of difference than to study their points of resemblance, and so form them into definite groups in which, while the members might differ slightly from one another, their main characteristics

would enable them to be distinguished from the members of other groups. In other words, I would suggest the study of the affinities as well as the differences of the organisms. In that case, even if one might not be quite certain if the organism was a new species, he would know approximately where to place it.

It may, perhaps, not be out of place to quote the following passage from my report made in 1891 (though no doubt the idea has occurred to others):

"The result of the large number of disjointed efforts made in the direction of systematic description of the water bacteria makes it clear that the matter can never be settled on paper or by the isolated observations of individuals. What is wanted seems to be more co-operation among those working on the subject. This would lead to a sounder basis of classification of the water flora and seems really to be the only feasible means of attaining that end. If a society or committee of those engaged in water analyses in different localities could be formed, and each member allotted one group to investigate, so that various organisms of the same group obtained from different localities could be compared by parallel cultures, the results when compared and published would soon form a recognized standard of comparison. This would not only help beginners, but would obviate to some extent the causes which tend to confuse the work."

Not feeling myself competent to take the lead in a project of this sort, I refrained from taking any steps in the matter, but it may be mentioned that with the co-operation of Professor Adami, of Montreal, an attempt is now being made to organize somewhat upon the lines just laid down a scheme for the co-operative study of the water bacteria.

Bacteria Found in Montreal Water.—The forms which occurred were almost exclusively bacilli, only two species of micrococci being met with.

During the pollution due to heavy rains and melting snow a considerable number of molds, were present. A form of *Fusarium* was once detected in tap water.

The relative proportions of the species present often gave valuable indication of slight degrees of pollution when the total

number of colonies was not sufficient to attract attention * and certain species, notably B. mycoides, appeared when the water was exposed to the washings of cultivated land.

As a rule 5 to 7 forms were detected in each sample when the water was pure, while in impure samples from the Montreal harbour, I have isolated as many as 16 species from the sample. On the other hand when a large number of bacteria developed in stored waters which were pure nearly 90 per cent of the colonies would belong to one species, usually *B. Fluorescens liquefaciens*, and if during the summer the proportion of this organism (which was normally from 30 to 40 per cent of the total colonies) fell to below 12 per cent, other proofs of pollution were usually forthcoming.

A singular circumstance was that in winter this ratio fell to 5 or 10 per cent., although the water was pure, the proportion suddenly rising again when the warm weather returned, while *B. Aquatilis* and other members of the yellow pigment-forming group formed the leading flora during winter. This transition is shown in the following table of analyses :

No.	Sample.	Date.	Temp. of water.	Bacteria per c.c.	B. Flunesc. liq. %	B. Aquatilis, %
128	Tap	May 6, 1891.	6°	646	4	·30
129	Tap	May 7	6°	860	8	35
146	Tap	May 14	10°	106	15	20
143	Reservoir	May 14	13°	106	15	20
140	Basin	May 13	11·5	146	12	20
138	St. Cunegonde	May 13	10°	189	15	15
131	St. Lawrence	May 13	9°	245	10	25
155	Tap	June 4	11·5	140	40	2
156	St. Lawrence	June 5	14°	123	30	4

The following were among the common forms met with in Montreal water :

B. arborescens, *B. aquatilis*, *B. flourescens*, *B. fluorescens liquefaciens*, *B. janthenus*, *B. glaucus*, *B. megatherium*,

* See page 21.

B. multipediculus, *B. mycoides*, *B. nacreosus*, *B. aurantiacus* *B. ramosus*, *B. aquatilis sulcatus*, *B. mesentricus vulgatus*, *B. mesentericus fuscus*, *B. proteus*, *B. fulvus*, *B. fuscus*, *B. ochreceus*, *B. plicatus*, *B. implexus*, *B. ruber.*

Among the rare forms may be mentioned B. Berolinensis, of which one single colony was met with.

Spirilla were not detected, but it must be mentioned that the plan of cultivating in weak peptone solutions was not known at the time.

I was able by means of the Parietti and Péré methods to isolate forms apparently belonging to colon group, but never succeeded with Montreal water in finding a perfectly typical distinctive culture of *B. Coli* or *B. Typhi*, whereas I found these present in some spring water at a village where typhoid was epidemic.

CONCLUSIONS.

From the result of this analysis it appears :

1. That the Montreal water is of good quality, as compared with other surface water, and does not appear to be at present a source of danger to public health, though its future purity is not altogether assured.

2. That from a biological point of view the St. Lawrence water is not superior to that of the Ottawa.

3. That the St. Cunegonde site offers no advantages.

4. That the reservoir water is superior to that of the settling basin, and that the Ottawa water is well adapted for storage in open reservoirs.

5. That better facilities for settling water should be provided, and no water pumped into the mains without previous sedimentation.

Inasmuch as the extreme severity of the winter makes the employment of filtration impracticable, it is necessary to watch very carefully any minor sources of possible pollution, especially those lying between the settling basin and St. Anne.

It would be advisable to make experimental studies upon the dimensions and capacity of a suitable settling basin, and also to make arrangements by which the water could be

examined regularly at weekly or fortnightly intervals in order that any variations from the usual standard of purity established by these analyses may be promptly investigated. It would also be well to see if a better quality of water could not be obtained from the Lake of Two Mountains, and to investigate the amount and quality of water available in the lakes in the Laurentian Mountains, lying to the north, in case of a change of supply becoming necessary in the future.

I have to record my thanks to Mr. A. Davis, Superintendent of the Montreal Water Works, for having obtained permission to publish the foregoing report, and also for kindly loaning the cuts which illustrate it.